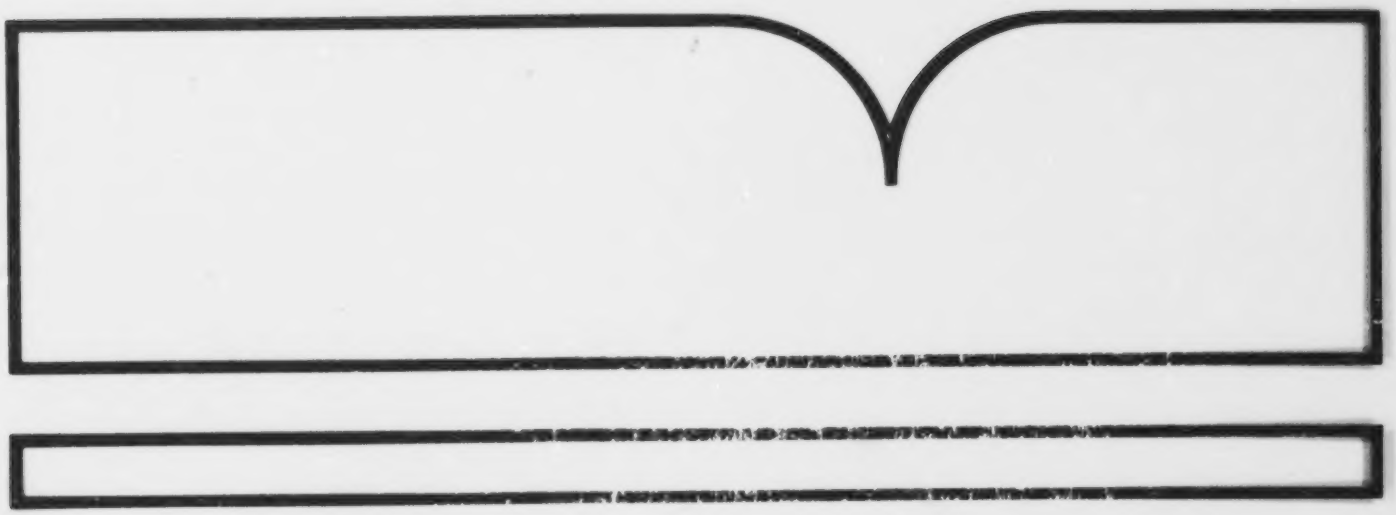
PB85-157030

Evaluation of a Method for Estimating Pollution Concentrations Downwind of Influencing Buildings

(U.S.) Environmental Sciences Research Lab.
Research Triangle Park, NC

1984



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TECHNICAL REPORT DATA (Please read Instructions on the reverse before complet		
1. REPORT NO. EPA/600/J-84/208	2.	3. PB85-157030
4. TITLE AND SUBTITLE EVALUATION OF A METHOD FOR ESTIMATING POLLUTION CONCENTRATIONS DOWNWIND OF INFLUENCING BUILDINGS (Journal Version)		5. REPORT DATE 1984 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Alan H. Huber		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Meteorology and Assessment Division Environmental Sciences Research Laboratory U.S. Environmental Protection Agency Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO. CDTA1D/09-2056 (FY-83) 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Sciences Research Laboratory - RTP, NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/09

15. SUPPLEMENTARY NOTES

REF: ATMOSPHERIC ENVIRONMENT, 18(11):2313-2338, November/December 1984

16. ABSTRACT

A simple method for estimating enhanced dispersion resulting from the overall effect of buildings is presented and evaluated. A framework for applying the method to general plume dispersion modeling problems is suggested and examples are provided. The Gaussian plume equation has been modified to incorporate building wake enhanced dispersion parameters, and the resulting ground-level plume centerline concentration estimates are compared to 10 sets of field measurements. The results indicate that the method can provide a good correction for the overall effect of adjacent buildings.

Better measurements of plume height and the vertical spread of the plume are still needed to resolve some issues. The effect of building influences on plume rise and the determination of plume centerline requires vertical profile measurements. Also, the effect of wind speed should be considered. The cases with the highest wind speed have been observed to behave somewhat extraordinary for several of the studies. Also, the possible effect of vortices should be more fully evaluated. Additional data are needed to fully examine building wake effects. However, in lieu of site-specific information, the methods presented in this report should provide an approximate correction to estimated ground-level centerline concentrations.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

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INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	28
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

EPA/600/J-84/208
JOURNAL ARTICLE

Atmospheric Environment Vol. 18, No. 11, pp. 2313–2338, 1984
Printed in Great Britain.

0004–6981/84 $3.00 + 0.00
Pergamon Press Ltd.

EVALUATION OF A METHOD FOR ESTIMATING POLLUTION CONCENTRATIONS DOWNWIND OF INFLUENCING BUILDINGS

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(*First received* 7 *September* 1983 *and in final form* 30 *April* 1984)

Abstract—A simple method for estimating enhanced dispersion resulting from the overall effect of buildings is presented and evaluated. A framework for applying the method to general plume dispersion modeling problems is suggested and examples are provided. The Gaussian plume equation has been modified to incorporate building wake enhanced dispersion parameters beyond the wake cavity region, and the resulting ground-level plume centerline concentration estimates are compared to 10 sets of field measurements. The results indicate that the method can provide a good correction for the overall effect of adjacent buildings. The effect of building wake enhanced dispersion on maximum ground-level concentrations is to decrease their values for releases near ground-level and to significantly increase their values for elevated releases. For elevated releases, enhanced horizontal dispersion dilutes the plume more rapidly; enhanced vertical dispersion also rapidly dilutes the plume but it can also bring the plume to ground-level while the in-plume concentrations are still high.

Key word index: Air pollution, atmospheric diffusion, dispersion, turbulence, building downwash, wake, meteorology, air quality models, model evaluation, field studies, pollution concentration distributions, plumes.

1. INTRODUCTION

The effect of buildings on pollutant dispersion often is an important aspect of air quality impact analyses. A plume that is entrained in the wake of a building can result in ground-level concentrations that are significantly different from those measured in the absence of a building. In a series of wind-tunnel studies conducted at the Environmental Protection Agency (EPA) Fluid Modeling Facility by Huber *et al.* (1980), smoke visualization photographs and concentration profiles were used to measure the effects of the building wake on dispersion from elevated point sources. Observations showed that the vertical dispersion in the immediate wake of the building was greatly enhanced. For a case where the effluents were emitted into the cavity (at the lee of a building), rapid horizontal spreading was also observed. A simple mathematical model for estimating the enhanced dispersion in the wake of the building was found to perform well for the particular situation of the study (Huber and Snyder, 1982). Beyond the region of noticable building wake influence, a virtual source distance adjustment helped to accurately predict building influence. The method used by Huber and Snyder (1982) is believed to be generally applicable to other similar building-source configurations. A framework for applying the method to general plume dispersion modeling problems is presented in Section 2. The method and ideas presented in this paper should be taken as a first-order approach to adjusting plume dispersion caused by the overall effect of buildings or obstacles. The method should be applied only to pollutant sources that are near the building, and the estimated concentrations are most appropriate at downwind distances beyond the highly turbulent flow of the immediate building wake. The method is not appropriate for estimating concentrations within the wake cavity region where the build-up of concentrations is associated with residence times (e.g. Vincent, 1977). Section 3 presents an analysis of model estimates compared to 10 sets of field data.

The basis of the method evaluated in this paper is briefly discussed here. Additional discussions on building wake effects and procedures for estimating pollutant concentrations downwind of buildings can be found in summaries of current literature (e.g. Meroney, 1982; Hosker, 1984).

In the immediate lee of a building, there is a 'cavity' region where the building wake flow is recirculated, mean velocities are reduced, and the air flow is highly turbulent. The flow in the building wake farther downstream is characterized by a turbulence intensity that progressively decays to background levels. Intuitively, a plume that is initially subjected to the wake effects of a building should have cross-plume concentration distributions that are influenced by the size of the building. Initially, one would expect that the vertical and horizontal plume dispersion would be a

*On assignment from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

function of the height and width of the building. Beyond distances where the building influences are noticable, the growth in plume dispersion will be controlled by ambient turbulence; thus, in time, the plume will appear to be free of the initial effect of the building. Moreover, the rate of plume growth beyond the initial influence of the building would relate to its actual size. Thus, calculation of plume growth by use of a virtual source distance is appealing. The general function presented in Section 2 for estimating plume dispersion parameters in the near wake of buildings is quite simple. Alternative formulas for the near wake region may be adopted from site-specific data. The idea of using a virtual source distance for calculations beyond the near wake region should be universally valid and is the key point of discussion throughout the field study evaluations.

2. DISPERSION ENHANCEMENT AND DOWNWIND PLUME CONCENTRATIONS

The Gaussian plume equation for estimating the normalized ground-level centerline concentration is

$$\frac{\chi U}{Q} = \frac{\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]}{\pi\sigma_y\sigma_z} \quad (\mathrm{m}^{-2})$$

where

χ = pollutant concentration ($\mathrm{gm\,m^{-3}}$),
U = the mean wind speed at release height ($\mathrm{m\,s^{-1}}$),
Q = emission rate ($\mathrm{gm\,s^{-1}}$),
H = plume centerline height above the receptor (m) and
σ_y, σ_z = the values of the horizontal and vertical dispersion parameters (m) (i.e. standard deviation of plume profile that is presumed to have a Gaussian concentration distribution).

Three simple models are presented for estimating enhanced dispersion parameters in the wake of buildings. Model I is based on the results of Huber and Snyder (1982). Equations (1a) and (1b) are to be applied in the near wake region (i.e. 3–10 building heights). Dispersion in this region is assumed to be independent of ambient turbulence. In the assumed far wake region (i.e. greater than 10 building heights), Equations (1c) and (1d) apply a virtual source distance adjustment to known ambient dispersion parameters. No estimates within the cavity region (i.e. three building heights) are considered appropriate due to great variability and uncertainty.

Other simple models, which attempt to account for enhanced dispersion in the lee of buildings, are contrasted to Model I and are outlined below. The concept of adding a 'looping' component to the plume centerline, as presented by Gifford (1968), is described by Model II. A looping movement of the plume in the lee of the building is the result of oscillating vortices induced by the flow over the building. These vortices are proportional in size to the building dimensions. In this evaluation, the looping component was chosen to correspond to the initial plume dispersion for Model I. Lastly, Gifford (1968) presents the model described here as Model III. This model for enhanced dispersion is based on dilution of the effluent into the cross-sectional area of the building. Depending on the choice of the constant and the relation of building area to the scale of the looping plume, Model III can be similar to the form of Model II.

Model I:

$$\sigma_y' = 0.7\,W_b/2 + 0.067(x - 3H_b);\ \text{for } 3H_b < x < 10H_b \quad (1a)$$

$$\sigma_z' = 0.7\,H_b + 0.067(x - 3H_b);\ \text{for } 3H_b < x < 10H_b \quad (1b)$$

$$\sigma_y' = \sigma_y(x + S_y);\ \text{for } x \geq 10H_b \quad (1c)$$

$$\sigma_z' = \sigma_z(x + S_z);\ \text{for } x \geq 10H_b \quad (1d)$$

Model II:

$$\sigma_y' = [\sigma_y^2 + (0.7\,W_b/2)^2]^{1/2};\ \text{for } x > 3H_b \quad (2a)$$

$$\sigma_z' = [\sigma_z^2 + (0.7\,H_b)^2]^{1/2};\ \text{for } x > 3H_b \quad (2b)$$

Model III:

$$\sigma_y' = (\sigma_y^2 + CA/\pi)^{1/2} \quad (3a)$$

$$\sigma_z' = (\sigma_z^2 + CA/\pi)^{1/2} \quad (3b)$$

where

x = distance downwind of the leeward edge of the influential building,
$W_b/2$ = "half-width" of the region of influential buildings normal to the wind,
H_b = height of highest influential building,
S_y = the virtual source distance such that $\sigma_y'(10H_b) = 0.7\,W_b/2 + 0.5\,H_b$,
S_z = the virtual source distance such that $\sigma_z'(10H_b) = 1.2\,H_b$,
σ_y, σ_z = the values of the horizontal and vertical dispersion parameters in absence of building influences,
A = cross-sectional area of the buildings normal to the wind and
C = a constant.

Models I and II are based on the concept that the scale of mixing in the immediate lee of a building is related to the length scales of the building. The models for enhanced dispersion are to be applied only to sources placed near a building (e.g. within $2H_b$) and lower than 2.5 times the height of the building or, in the case of tall buildings, a height of $H_b + 1.5\,W_b$ as discussed by Snyder and Lawson (1976). Also, for buildings that are much taller than they are wide, only the width scale, W_b, is significant and should replace H_b as the scale used in estimates of σ_z'. For buildings that are much wider than they are tall, only the height scale, H_b, is significant, and it should replace W_b in estimates of σ_y'. Additional data are needed to verify these points;

nonetheless, they are intuitively appealing as a first approximation.

In Model III, the constant, C, is based on the amount of effluent enveloped by the building wake and an estimation of the relation of the size of the wake to the cross-sectional area of the buildings. Values for C in the literature range between 0.5 and 2.0 (when all the effluent is dispersed into the wake). Model III is a general form of Model II (i.e. C and A may be chosen); therefore, it usually will not be discussed separately.

As an example, Models I and II are applied to a building that is 25 m high and 50 m wide. Figure 1 presents the modification to the Pasquill–Gifford horizontal and vertical dispersion parameters pre-

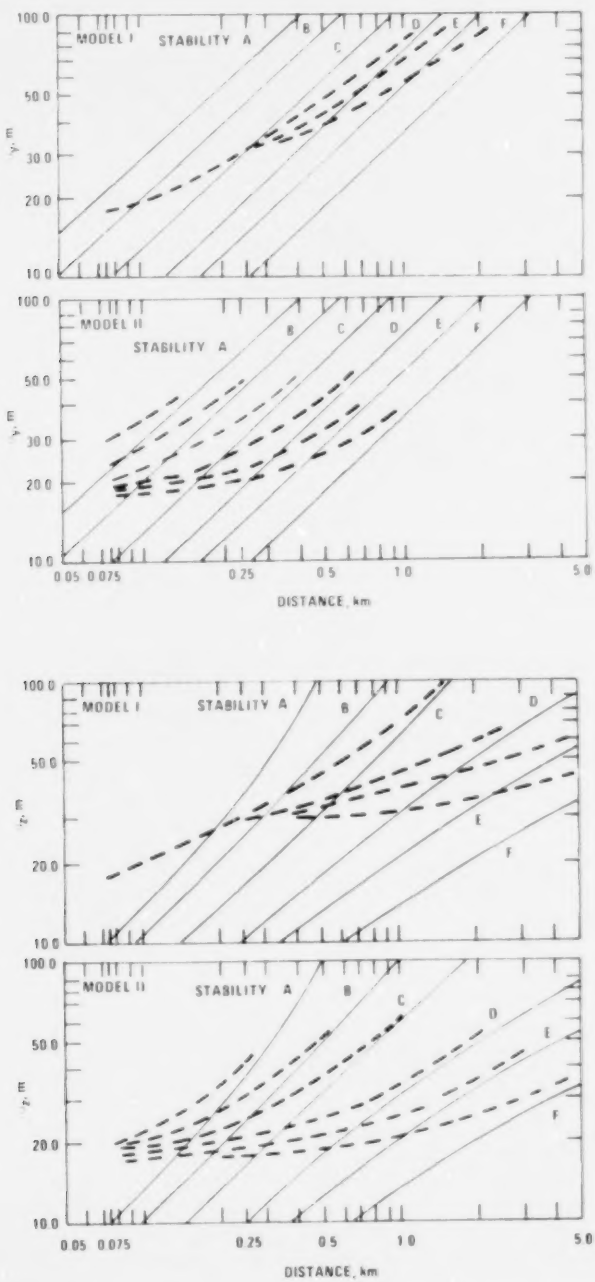

Fig. 1. Modifications to the dispersion parameters of Pasquill–Gifford (Turner, 1970) for a building 25-m high × 50-m wide.

scribed by these models. In applying Model I, if the unmodified dispersion parameters are greater than those prescribed by the model, then no modification is made. That is, the building cannot reduce the dispersion from that which would occur in the absence of the building. The major difference between the two enhancement models is that for the more stable curves (particularly E and F), the values prescribed by Model II are significantly smaller and approach the unmodified values more rapidly than the values of Model I. In all cases, the modified values are nearly equivalent to the unmodified values at a downwind distance of $100\,H_b$, and they are much nearer to the unmodified values under neutral and unstable conditions.

The discussion by Gifford (1976) on diffusion in the lee of flow obstacles indicates two major defects in employing the area dilution concept. First, reviewed studies indicate that the building wake persists much farther downstream in neutral and stable conditions than estimates that are comparable to those described by Model II or Model III would indicate. This result is also what was observed in the current evaluation. The building effects using Model I were found to persist much farther downstream than those using Model II (Fig. 1). Secondly, ambient and wake-induced turbulence under low wind speed and stable atmospheric conditions is affected by erratic larger-scale horizontal meander in the flow direction. This influence suggests the need for an understanding of the ambient effects on plume spread, before the building effect is included. In particular, estimates for stability classes E and F should be made with caution because the building effects may be somewhat reduced under stable atmospheric conditions with light winds (i.e. $< 3\,\mathrm{m\,s^{-1}}$). Also, field studies reported by Halitsky and Woodward (1974) and Start *et al.* (1977) seem to indicate that the large horizontal meander of the wind near the earth's surface may have a far greater influence than the building wake effects.

Models I, II and III are more applicable to sources placed along the building centerline axis with the wind because the concenration pattern from sources situated off the centerline of the building is likely to be more complicated than that for emissions into a symmetric wake. However, the models should be generally applicable. Thompson and Lombardi (1977) studied roof-vent emissions and found that a change in the direction of the approaching wind significantly alters the shape and size of the cavity and dispersion patterns very near the building. However, ground-level concentrations in the study were essentially equal for the 0 and 45° wind incidence cases, beyond a distance of about $10\,H_b$. Some discussion in the literature concerns the influence of vortices generated by the building; however, the possible significance of their effect on plume dispersion has not been demonstrated. An appreciation for the complexities of the flows in wakes and the great dependence of the flow on the particular wind field at a given time can be quickly gained by observation. Model I and the applications discussed above are offered as reasonable techniques for estimating the enhancement of plume dispersion in the wake of a building. When possible, individual field studies or fluid modeling studies are preferred, particularly when high concentrations near the building are an important aspect of the study.

A demonstration and an examination of the effects of incorporating the above ideas and modifications to known ambient dispersion parameters into the basic Gaussian plume equation (Turner, 1970) are assessed through the application of these modifications to a building that is 25 m high and 50 m wide. Figure 2 represents estimates of ground-level normalized centerline concentrations for various plume heights. The dashed lines indicate the concentrations calculated using the enhanced dispersion parameters (Model I), while the solid lines represent those concentrations calculated using the ordinary Pasquill–Gifford dispersion parameters (Turner, 1970) for stability classes B, C and D. For sources at ground-level or at building height, both horizontal and vertical dispersion are enhanced; however, this results in lower concentrations for only the ground-level source. For the elevated sources, the building wake modification results in greater maximum concentrations, which occur closer to the source. This increase in the maximum concentration is least for the tallest source.

Figure 3 presents comparisons among the stability categories A–F for emission heights, H_s, equal to 0 and 37.5 m (i.e. $H_s/H_b = 0$ and 1.5). For Fig. 3(c), only the vertical dispersion parameter is enhanced. These figures show how the overall maximum ground-level concentrations may be affected by buildings. Any building enhancement of plume dispersion for ground-level releases will result in lower concentrations in all locations. However, for elevated releases, there is a 'play' between the values for the vertical and horizontal dispersion parameters. The maximum ground-level concentrations are very sensitive to the value of the vertical dispersion parameter. For elevated releases, enhanced horizontal dispersion dilutes the plume more rapidly; enhanced vertical dispersion also rapidly dilutes the plume but it can also bring the plume to ground-level while the in-plume concentrations are still high.

3. FIELD STUDY EVALUATIONS

Overview

Ten field study databases are used to evaluate building wake effects. In each study, measured ground-level centerline concentrations are compared to modeled centerline concentrations. Measured lateral ground-level dispersion parameters are compared to model estimates in several studies. In two studies, measured enhancement of vertical and horizontal turbulence in the building wake is compared to the model enhancement of the plume dispersion par-

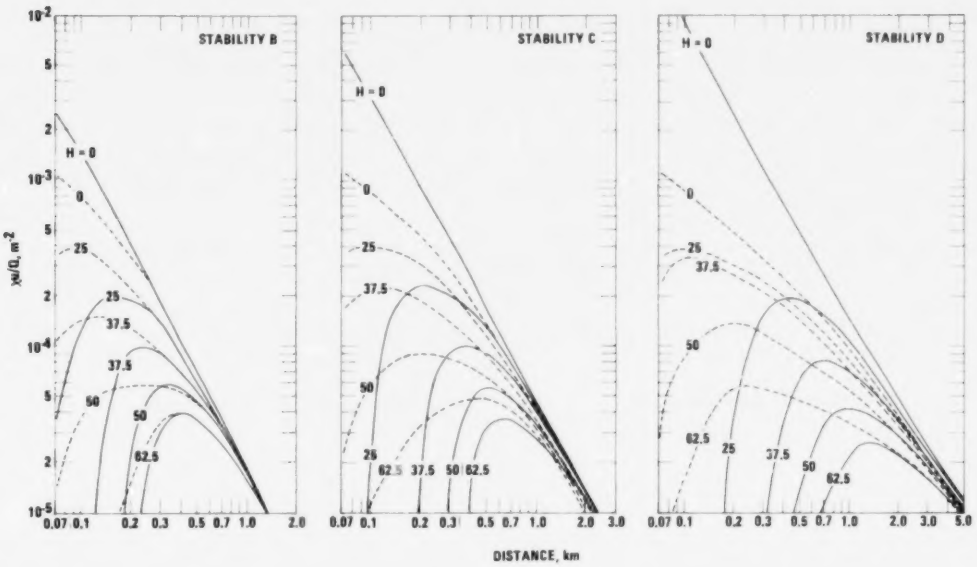

Fig. 2. Comparison of concentration estimates with (– – –) and without (——) dispersion enhancement resulting from building wake effects for various heights of emission, H_s (H_b = 25 m, W_b = 50 m).

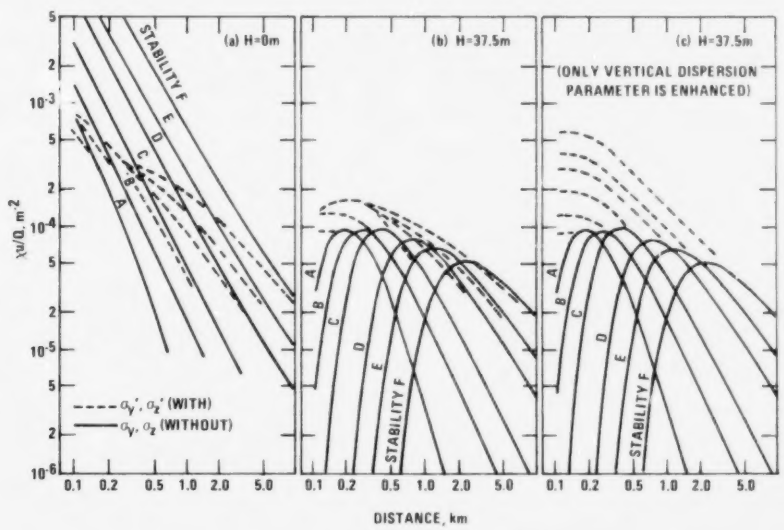

Fig. 3. Comparison of concentration estimates with (– – –) and without (——) dispersion resulting from building wake effects for assumptions a, b and c (H_b = 25 m, W_b = 50 m).

ameter. Only one study provided a limited number of tests that included a measurement of the vertical profile of the plume. Thus, field measurements of plume centerline height and vertical dispersion are inadequate to provide a complete plume evaluation. Nonetheless, the performance of the simple enhanced dispersion concepts can be indirectly evaluated. Additional field measurements (including vertical plume profiles) are needed to provide a complete base for evaluating model improvements. Measured concentrations beyond 10 building heights (and farther than 100 m) are best suited for the study because of assumptions inherent in the modeling methods being evaluated.

Unless otherwise noted in the following analyses, the model concentrations all refer to Gaussian plume equation estimates based on Model I dispersion enhancement. The building width, building height and

plume centerline height used in the equation are noted for each study. Ambient dispersion is assumed to be characterized by Pasquill–Gifford (Turner, 1970) stability classes A–F throughout the analyses. Stability classes 1–6, corresponding to stability classes A–F, are used in some of the analyses to provide different groupings. For instance, one grouping in the following figures may correspond to data for a ground-level release while the other may correspond to data for an elevated release. Also, in several of the following figures, data points are displaced along the distance axis so that they are legible. Vertical axes are displayed along with these data in a few figures to indicate the correct distance for the data points.

3.1. *Evaluation of individual field studies*

Islitzer (1965). Measurements of both atmospheric turbulence and dispersion of a fluorescent tracer downwind of the MTR–ETR reactor complex in southeast Idaho were presented by Islitzer (1965). The complex consisted of a reactor building (25 m high) plus a number of smaller buildings. The group of smaller buildings as a whole was estimated to have an effective width of 160 m. The tracer was released at ground level from a point downwind of the reactor building. A sampling grid was set up to determine the horizontal plume spread, and the most distant sampling line was at 850 m. The results of nine cases from a ground-level release under unstable atmospheric conditions were evaluated.

The curve connecting mean estimates of measured dispersion for the nine cases is presented in Fig. 4. Model estimates were also made for the MTR–ETR complex. The model estimates, assuming ambient stability class B, were in good agreement with the data. In the estimates for Model III, an estimated value of the projected cross-sectional area of the buildings, A, was fixed at 2400 m^2 while the constant, C, was varied from 0.5 to 2.0.

For the nine cases, the means of the 30-min sample (4-s averages) values of wind turbulence (vertical and horizontal standard deviations of the wind directions, σ_ϕ and σ_θ) at the 6-m level downwind of the building are presented in Fig. 5. Very near the building, the

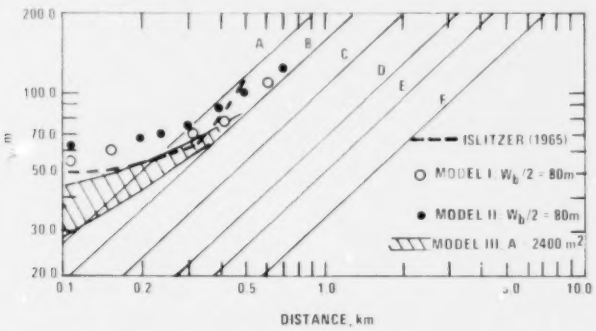

Fig. 4. Comparison of modified lateral dispersion parameters with field data of Islitzer (1965).

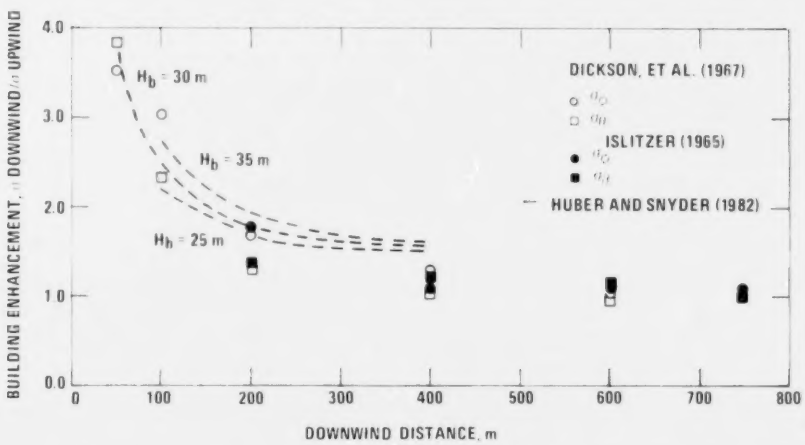

Fig. 5. Building enhancement effect on wind turbulence compared to Huber and Snyder (1982)'s estimate of dispersion enhancement.

vertical and horizontal turbulence was primarily aerodynamic. Further downwind, where the aerodynamic turbulence had decayed, the turbulence intensities returned to their upwind atmospheric values. Figure 5 presents the average building enhancement effect (ratio of turbulence downwind to turbulence upwind from the building). The ratio decreased to almost 1.0 at a distance of 10 building heights downwind. The building enhancement of the turbulence parameters, within about $5H_b$ of the building, followed the observed enhancement of the dispersion parameters downwind of a rectangular building modeled in a wind-tunnel (Huber and Snyder, 1982), which is equivalent to Model I estimates within these distances.

The measured concentrations and model estimates are presented in Fig. 6. Model estimates with enhanced horizontal and vertical dispersion parameters and H_b = 25 m and W_b = 160 m accurately accounted for the

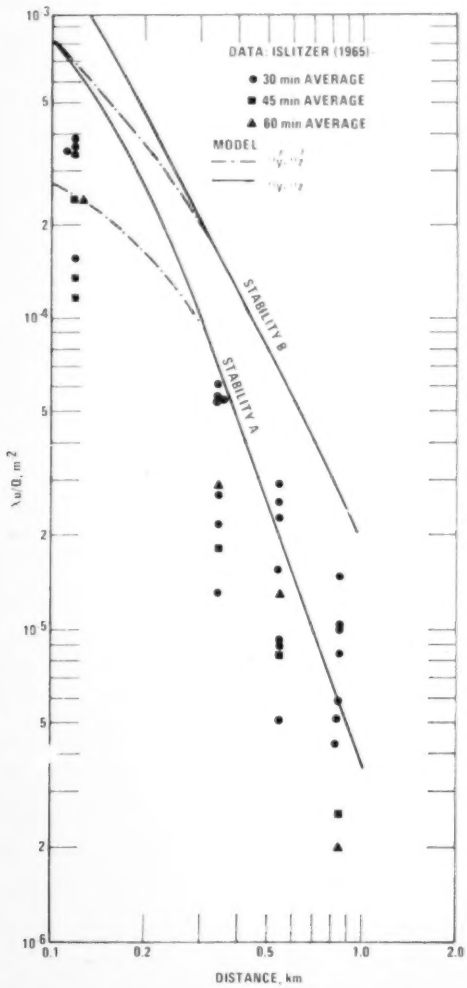

Fig. 6. Comparison of model estimates with measured concentrations for a groundlevel release (Islitzer, 1965).

average effect of the building found at the 118-m arc of receptors. The measured concentrations and model estimates at the receptors farther downwind indicated that the building did not influence atmospheric dispersion when the background atmospheric condition is assumed to be very unstable.

Martin (1965). A study of atmospheric dispersion of krypton-85 tracer emitted from the stacks at the Phoenix Memorial Laboratory on the University of Michigan campus was conducted by Martin (1965). The site consisted of a 14-m reactor building connected to the laboratory and several nearby buildings. The stack heights were 3 m above the roof of the reactor building, and the building was found to have a definite influence on plume dispersion. Thirty-three field tests were conducted using a network of 10 ground-level samplers for each test. Data from two tests have been presented by Culkowski (1967). These tests were selected because ground-level measurements were made over a comparatively uncluttered downwind surface area.

The modified model estimates were made with enhancement of only the vertical dispersion parameter because the stack height is greater than 1.2 times the building height. A small plume rise is likely for the lighter wind case (U = 2.25 m s^{-1}), so estimates were made for a 20-m plume centerline height. As Fig. 7 shows, the modified model estimates with H_b = 25 m agree with the reported data. The reported concentration values are much greater than estimates made by assuming no building influence.

The data seem to indicate that the plume was drawn entirely to the ground by the aerodynamic wake of the building and appears like a ground-level source with no wake enhancement beyond 70 m ($5H_b$). Such behaviour is similar to that of a looping plume. The mechanical turbulence in the wake of the building should cause some enhancement of the plume over a time greater than a few minutes. The averaging time of Martin's data has not been clearly identified, but is believed to have been only a few minutes. Comparison between the data and the model estimates would be best for samples that were measured for a period greater than 10 min. In both cases, the maximum concentration occurred near $5H_b$ downwind, which indicates that the release is elevated and that the plume may have been carried down to the surface along the boundary of the cavity region.

Dickson et al. (1967). Measurements of both atmospheric turbulence and dispersion of a fluorescent tracer downwind of the EBR-II reactor complex in southeast Idaho were presented by Dickson *et al.* (1967). The reactor containment dome and the nearby power plant were 29 and 19 m high, respectively. Smaller buildings were located throughout the complex. The group of smaller buildings as a whole was estimated to have an effective width of 130 m. Eight of the ground-level releases were conducted during unstable to neutral atmospheric conditions, and seven were conducted during inversions. The ground-level release point was

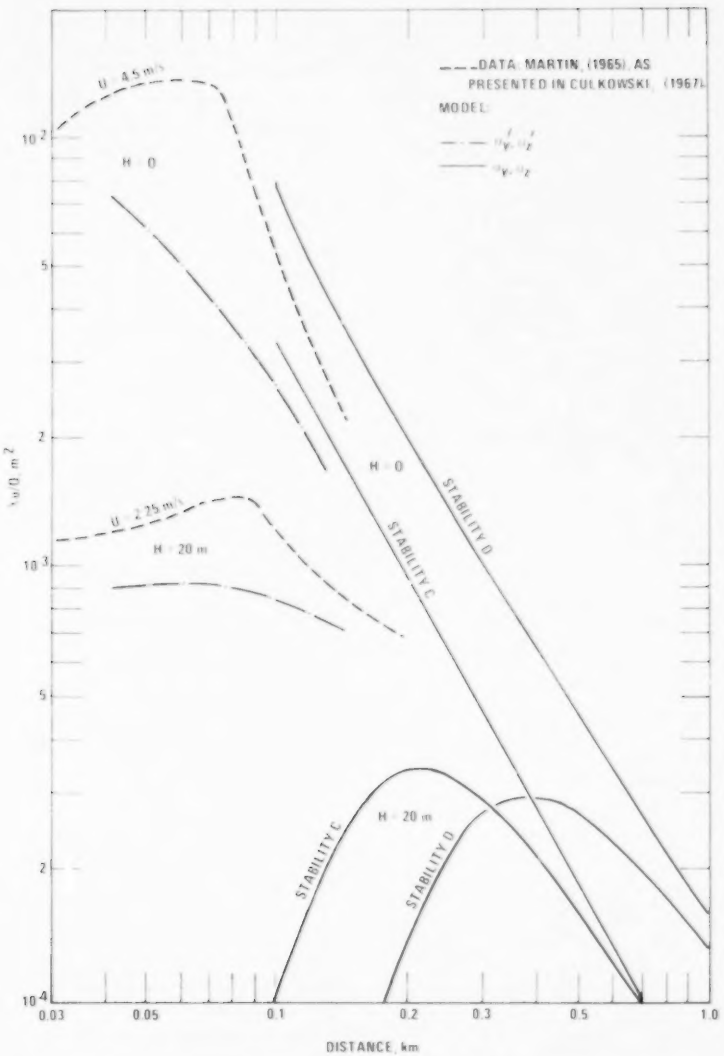

Fig. 7. Comparison of model estimates with measured concentrations for an elevated release (Martin, 1965).

located along the downwind surface of the containment vessel. The sampling grid was set up to determine the lateral plume spread downwind of the release point. The measured tracer concentrations represent 30-min averages.

For the EBR-II complex, the half-width was set at 65 m. Figure 8 compares the model-estimated enhanced dispersion, σ'_y, for Pasquill–Gifford stability classes B and E to the curve connecting the mean estimates of measured dispersion. In the estimates for Model III, the value of area A was set at 665 m^2 while the constant, C, was varied from 0.5 to 2.0. For unstable conditions, the measured σ_y rapidly approached the stability class B curve. For inversion conditions, the measured σ_y remained smaller and approached a lower stability curve. Field data beyond 1 km would be needed to confirm that the measured σ_y approaches the stability class E curve. The results from Model I and Model II were quite good. A slightly smaller estimate of the half-width, (e.g. 50 m) would provide excellent *a posteriori* estimates. Model III estimates were good for unstable conditions, but they significantly underestimated the dispersion during inversion conditions. A much larger value of building area A or constant C is needed to provide a good estimate.

The overall mean for the eight unstable to neutral cases and the seven stable cases of 30-min sample values of wind turbulence (σ_ϕ, σ_θ) at the 6-m level downwind of the building are included in Fig. 5. The overall mean is presented because differences in the upwind and downwind vertical and horizontal stan-

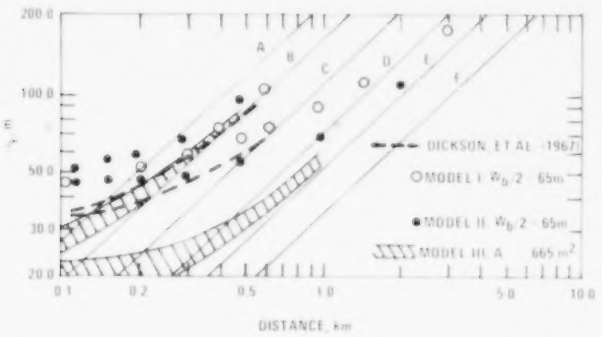

Fig. 8. Comparison of modified lateral dispersion parameters with field data of Dickson *et al.* (1967).

dard deviation of wind directions between the two groups were not observed.

In Figs 9 and 10, the measured concentrations are compared to model estimates. For both the stability classes C and D data in Fig. 9 and the stability class E data in Fig. 10, the estimates are quite comparable if only horizontal enhancement is used. This result implies that the vertical enhancement must be smaller than estimated. The horizontal enhancement is based on a width of 130 m that includes the contribution from several small buildings downwind of the containment vessel. The vertical enhancement is based on the

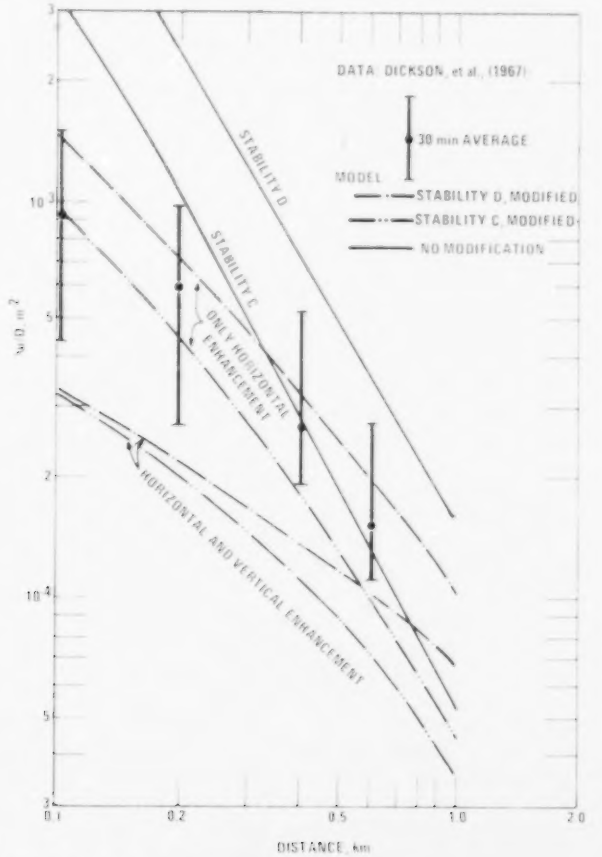

Fig. 9. Comparison of model estimates with measured concentrations for a groundlevel release during unstable-neutral conditions (Dickson *et al.*, 1967).

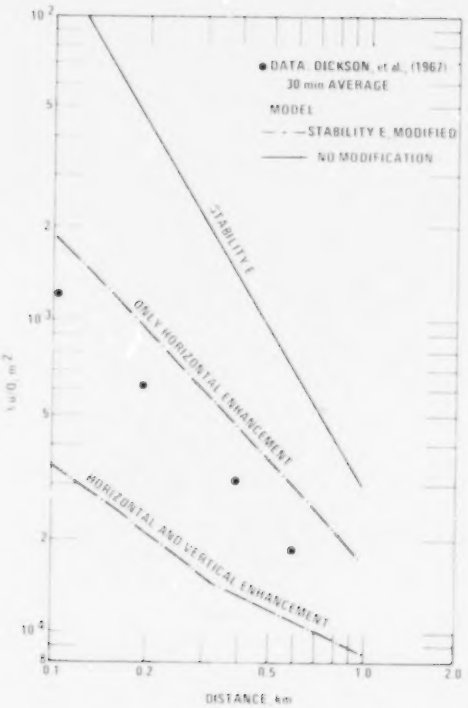

Fig. 10. Comparison of model estimates with measured concentrations for a groundlevel release during stable-neutral conditions (Dickson *et al.*, 1967).

vessel height of 30 m. The concentrations reported in Figs 9 and 10 are approximations from isopleths plotted in the referenced report. Each data point represents the centerline value based on isopleths for the mean of all cases, while the bar in Fig. 9 represents the range of maximum and minimum centerline values for the individual cases. Measured concentrations for both stability groups are nearly equal; this corresponds to the observed similarity for measured atmospheric turbulence.

Much of the horizontal enhancement probably occurred near the shorter buildings, so the part of the tracer above the height of these buildings was not affected. Thus, because the vertical enhancement would not be as large outside of the containment vessel wake, the centerline concentrations should be considerably higher than if similar vertical enhancement was presumed. Vertical concentration profiles would be necessary to verify this hypothesis. Also, because the containment vessel is round, the tracer released at the ground may not mix upward as has been observed for sharp-edged structures. The modified model estimates in Figs 9 and 10 are at least very similar in form, thus supporting the method used to estimate dispersion in the nearby wake region where mechanical mixing was predominant.

Munn and Cole (1967*a*). A study of atmospheric turbulence and dispersion at the Central Heating Plant at the National Research Council (NRC) in Ottawa, Canada, was reported by Munn and Cole (1967a). The plant was 40 m long, 15 m wide, and 18 m high, and had twin stacks rising 3 m above the roof. Plume rise varied between 3 and 15 m. Several other nearby major buildings probably influenced the fluorescent tracer dispersion. Twenty cases were conducted when atmospheric conditions were neutrally stable. The tracer sampling time for each case was 20 min, and the network consisted of six ground-level samplers. Only the measurements from four cases were adequate for the estimation of the plume centerline concentration. Seven other cases were used to estimate centerline concentrations from estimated isopleths. Therefore, the data should be interpreted cautiously.

For two trials, Munn and Cole (1967a) calculated the measured horizontal dispersion to be 40 m at 165 m downwind from the plant. The enhanced horizontal dispersion parameters were not estimated because a number of buildings surrounded the plant and were very close to the downwind samplers. Instead, the effective W_b was estimated by using the enhanced dispersion equation (1a), assuming a value of 40 m at 165 m downwind. The resulting value of 93 m for W_b was used to provide estimates of horizontal enhancement for all cases. This assumption probably is not accurate because the nearby buildings are grouped quite differently in each direction from the release stack.

Figure 11 presents the measured concentrations and concentrations estimated by the model; a source height of 30 m, which includes a final plume rise of 9 m, is assumed. The measured concentrations are much less than the estimates made by incorporating enhancement. Vertical enhancement appears to be overestimated, because the measured concentrations are nearly estimated by the values for stability class D, which assume no enhancement. However, the study reports the plume was undulating significantly. More likely, the concentration pattern was additionally complicated because measurements were made near other downwind buildings. Plume rise above the release level may also be a significant factor. Lawson (1967) discusses possible effects of plume rise and downwash for this study.

Munn and Cole (1967*b*). Munn and Cole (1967b) discussed the results of several tests they made at the CANDU Nuclear Power Generating Station at Douglas Point, Ontario, under conditions where the reactor buildings were likely to influence the dispersion from a nearby 45-m stack. The main building was 55 m long, 46 m wide, and 28 m high, and the nearby reactor dome was 44 m high and had a diameter of 42 m. Ground-level concentrations of a uranine dye tracer were measured along a downwind arc of seven samplers. The highest observed concentrations were reported for 11 tests. These values were not necessarily the true maxima because the samplers were either placed not on lines at right-angles to the wind or only part of the cross-wind arc contained measurements.

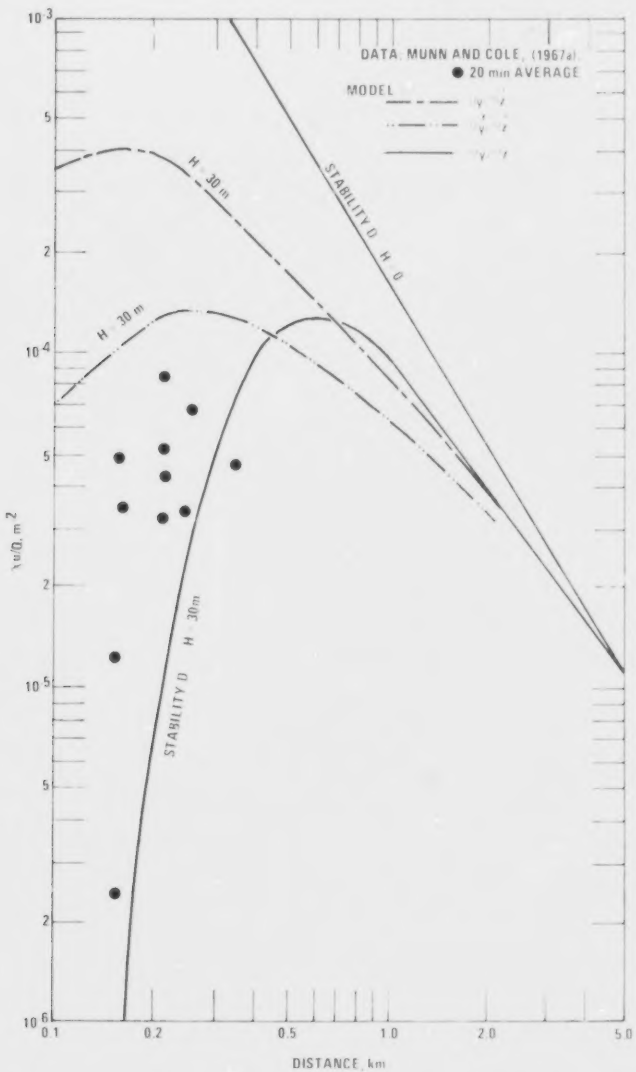

Fig. 11. Comparison of model estimates with measured concentrations for elevated release (Munn and Cole, 1967a).

For SSW winds, the samplers were placed very near the lee side of the reactor buildings, whose combined widths were approximately 100 m. The atmospheric stability during all tests was probably near neutral.

Figure 12 compares the data with model estimates. The measured concentrations are higher than estimates that assume no enhancement for an elevated release and a plume height of 50 m. The highest values are accurately estimated by incorporating only the enhanced vertical dispersion parameter based on the height of the main building, $H_b = 28$ m. Enhancement of the plume width should be expected for the tests conducted during SSW winds because the samplers were placed near a downwind building. No measurement of the spread was reported; thus, no comparison can be made. For some tests, the reactor dome may affect the plume. The model estimates that incorporate enhanced vertical dispersion and enhanced horizontal dispersion using W_b equal to 100 m for stability class D appear reasonable.

Cagnetti (1975). A study of uranine dye aerosol dispersion in the presence of buildings was reported by Cagnetti (1975). The tracer was released from a 14-m tower about 100 m upwind of a building that was 16 m high and 100 m wide. Two other buildings of similar size are located downwind. Nine diffusion trials were conducted during unstable atmospheric conditions. A 22-point sampling network around the nearby building was used during five of these experiments, and several different sampling times were used. The other

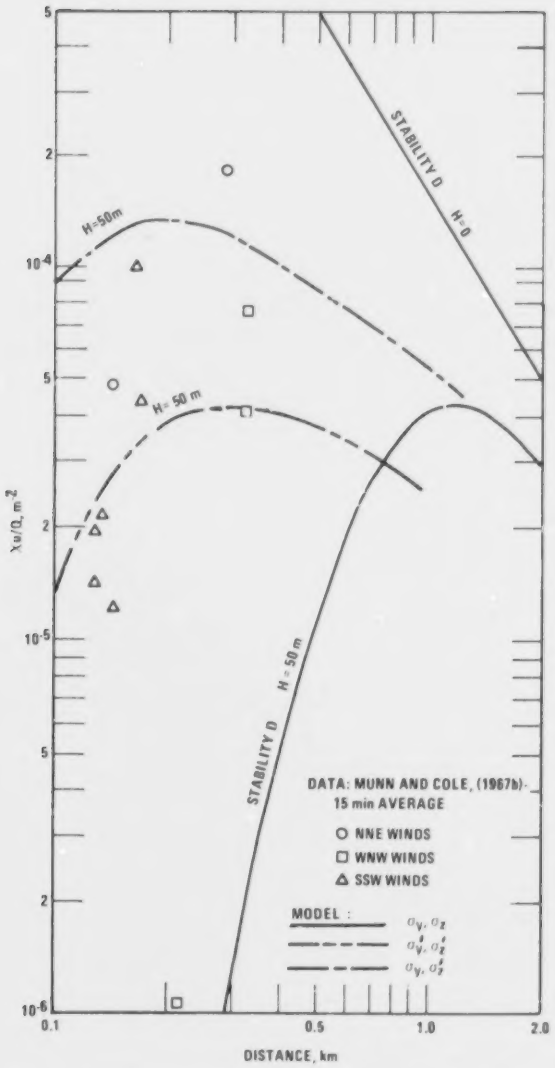

Fig. 12. Comparison of model estimates with measured concentrations for elevated release (Munn and Cole, 1967b).

four experiments were based on a network of 20 sampling points distributed over two crosswind lines at 450 and 850 m from the release point. The lateral plume spread was estimated for each of these trials. The effective width of the buildings downwind of these releases ranged from 100 to 200 m. The concentration patterns were apparently influenced by wind direction because of 'steering' between buildings.

The measured horizontal plume spread is smaller than estimated for the enhanced dispersion parameter using $W_b = 100$ m for stability class A and the measurements are no larger than values for stability class A unmodified dispersion parameters. However, the stack emissions are undoubtedly influenced by the buildings, as shown in Fig. 13. The measured concentrations are up to 10 times smaller than the estimates obtained by using enhanced vertical dispersion parameters where $H_b = 16$ m and enhanced horizontal dispersion parameters where $W_b = 100$ m. This result indicates that the vertical enhancement should be much larger than the estimates, because the horizontal enhancement is smaller than estimated. However, expectation of such a large vertical enhancement would not be realistic. The form of the profile for estimated concentrations is similar to that for measured concentrations. Some of the tracer intercepting the building may have been deposited or diverted to the side of the building; this would cause the lower maximum concentrations downwind of the building. Also, the building may have sheltered some of the samplers.

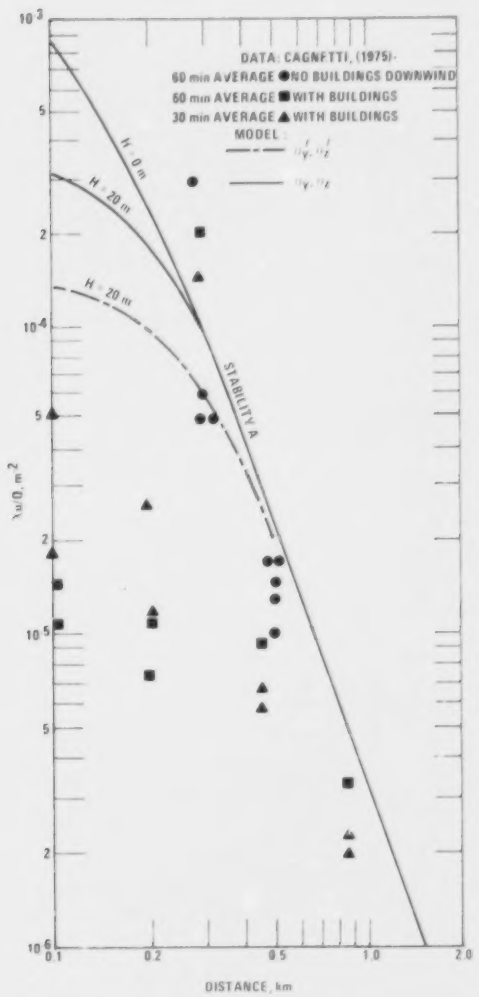

Fig. 13. Comparison of model estimates with measured concentrations for an elevated release (Cagnetti, 1975).

Johnson et al. (1975). Measurements of dispersion of sulfur hexafluoride (SF_6) from the reactor building vent and dispersion of dibromodifluoromethane (Freon-12B2) from a nearby turbine building were made at the Millstone Nuclear Power Station (Johnson *et al.*, 1975) located in southeastern Connecticut. The reactor building and the nearby turbine building were 45 and 28 m high, respectively. The entire group of buildings was estimated to have an effective width of 65 m. The release points were only several meters above the building roofs. Several other nearby buildings may also have had an effect on the dispersion of the vent emissions. Air samples were collected by 44 ground-level sequential multiple-bag samplers at three concentric 88-degree arcs at distances 350, 800 and 1500 m from the release points. The sampling grid provided sufficient data to estimate the horizontal plume spread. Data from 36 1-h-average cases were reported. Estimates of the measured horizontal plume spread were not included in the report.

The measured centerline concentrations for the releases out of the stack of the reactor building during neutrally stable atmospheric conditions are presented in Fig. 14. The measured concentrations have values that are categorized by the three ratios of effluent exit velocity to wind speed, W_s/U. The measured concentrations at 350 m downwind were much higher than those estimated for a 50-m release height without incorporating enhancement. The model estimates that incorporated the enhanced vertical and horizontal dispersion parameters assuming $W_b = 65$ m and $H_b = 49$ m were much less than most of the measurements. The measured concentrations for the tests with W_s/U less than 1.0 were larger than the model estimates, even with the assumption of no horizontal enhancement and zero height of release. These measured concentrations suggest that either the atmosphere was actually stable or that the vertical enhancement was less than that accounted for even with the assumption of zero release height. The estimates of measured concentrations for the tests when W_s/U is greater than 1.0 but less than either 1.4 or 2.15 are the most accurate. When W_s/U is less than 1.5, stack downwash influences are likely, and they may cause the significant differences among the tests. Overall, the profile of estimated concentrations appears in form to correctly account for the effects.

Bowers and Anderson (1981) used the reported measurements for stability class D conditions to graphically estimate the measured horizontal plume spread by assuming that the distance between the locations of concentrations that are equal to 10 per cent of the centerline concentration is 4.3 σ_y. At downwind arc distances of 0.35, 0.8 and 1.5 km, the mean measured σ_y values of 44.5, 87.5 and 139.5 m compare favorably to model estimates of 43.7, 67 and 110 m, based on $W_b = 65$ m. The high centerline measured concentrations may be an example of the adverse effects of vortices generated downwind of the building sides. These vortices could cause increased lateral spread at the surface while inhibiting plume spread above.

Thuillier and Mancusco (1980). A study of atmospheric dispersion of SF_6 tracer and visual smoke tracer emitted from three release points at different heights near the main building of the Duane Arnold Energy Center (DAEC) Palo, Iowa was reported by Thuillier and Mancusco (1980). The field-test area was basically flat with grass and wooded areas nearby. The highest release (12 cases) was from a vent at 46 m above grade. This vent (referenced here as the stack release) was situated on top of a 43-m building. Other elevated releases (16 cases) came from a capped roof-level vent (referenced here as the vent release) on top of a 24-m building. Ground-level releases were made near the building (11 cases) and away from the building (three successful cases). These buildings as a whole were estimated to have an effective width of 130 m near the

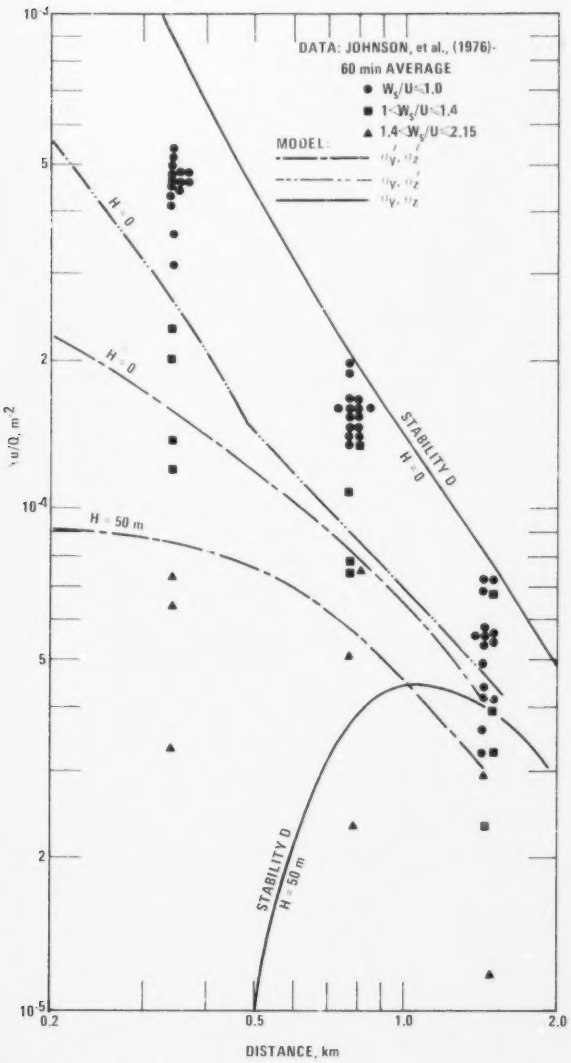

Fig. 14. Comparison of model estimates with measured concentrations for an elevated release (Johnson *et al.*, 1975).

ground but only 40 m above the 24-m roof level. Thus, it is believed that the stack release would initially be influenced by $H_b = 43$ m and $W_b = 40$ m but might be affected by $W_b = 130$ m when the plume was downwashed. The vent release would probably be affected by $H_b = 24$ m and $W_b = 130$ m initially, but its location near the taller structure might result in influence by $H_b = 43$ m. The sampling grid was arranged to determine surface concentrations and the lateral plume spread downwind from the DAEC complex at 0.3-km and 1-km arcs. Lidar profiles of the plume were also studied and compared with tracer measurements.

Figure 15 presents the lidar-measured vertical dispersion parameters. The one value for the stack release under light wind, stability class F conditions was observed in the field to be unaffected by the building and to rise well above the building roof level. Although the remaining measurements are scattered and limited in number, they are encouraging because both of the cases with two downwind profiles indicate a slow growth similar to the model estimate.

Figures 16 and 17 present the measured lateral dispersion parameters. Differences for release height and lidar vs tracer data are not significant. For many cases, the rate of plume growth follows the rapid rate characteristic of stability class A, thus suggesting that observable building influence is insignificant beyond 0.3 km. A few of the more stable cases show a trend comparable to that of the model estimates, assuming $W_b = 130$ m. The one very small value for stability class 5(E) corresponds to a case where the plume was observed to be unaltered by the building.

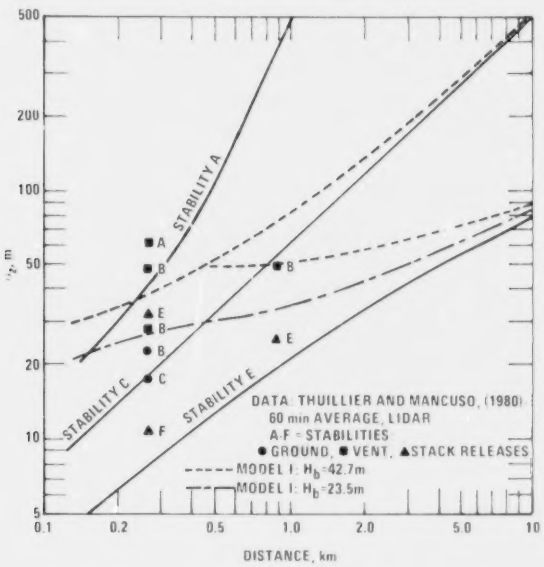

Fig. 15. Comparison of the modified vertical dispersion parameter with field data of Thuillier and Mancuso (1980), for ground, vent and stack release.

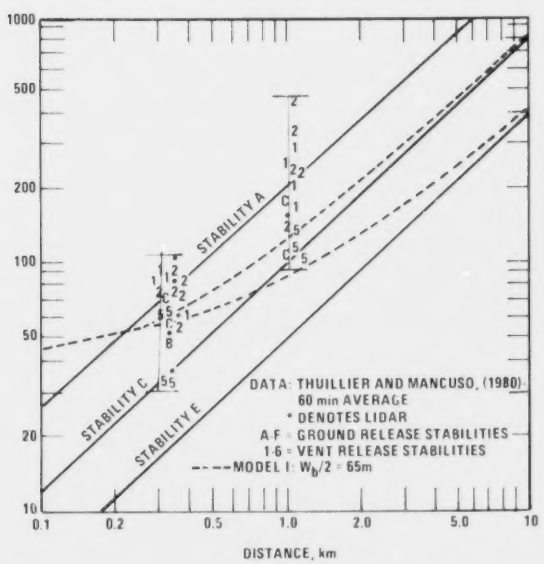

Fig. 16. Comparison of the modified lateral dispersion parameter with field data of Thuillier and Mancuso (1980) for ground and vent release.

Figure 18 presents the measured roof and ground-level release maximum centerline concentrations. The scatter in measured concentrations from the vent release for stability classes A(1) and B(2) conditions is rather large. The largest values for these data follow the model estimate for stability class C, and half of the remaining values nearly follow model estimates for stability class B (not plotted). The measurements for stability class E(5) at 0.3 km lie between the estimates for those concentrations with and without dispersion enhancement, while at 1 km, they lie closer to estimates without dispersion enhancement. The rate of decreasing concentration closely approximates the model rate change, but the values appear to be offset. Model

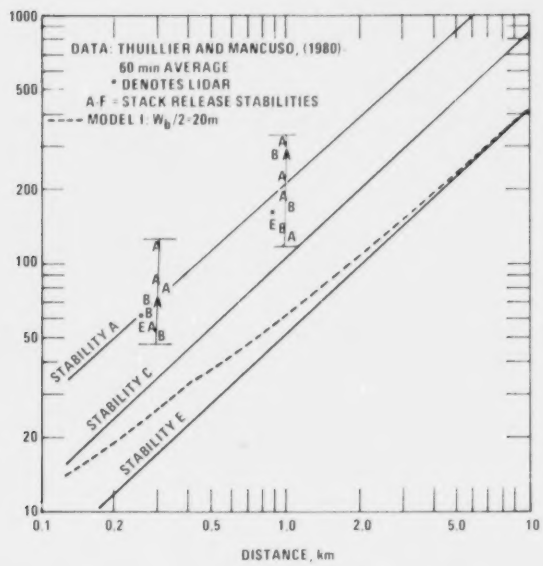

Fig. 17. Comparison of the modified lateral dispersion parameter with field data of Thuillier and Mancuso (1980) for stack release.

estimates for the ground-level release maximum centerline concentrations are predicted to be about 25 per cent larger than those for the vent release. Several of the measurements for conditions of stability class B agree with the model. However, the measurements for stability class C are 300 per cent larger than model estimates. In fact, the measured concentrations are larger than model estimates without dispersion enhancement. For these cases there is a trend toward model estimates of more stable conditions. This result contradicts the observations of the growth in the lateral dispersion parameters. Perhaps the growth in vertical dispersion is less. Similar results were found for the vent release cases. The stability class E(5) vent release represents cases that have the larger mean wind velocities for the study. Wind speed and possibly related factors may introduce significant differences. For instance, higher wind speed may result in greater direct downwash of the plume to the surface rather than diffusion. The range of the measured concentrations for the three ground-level releases away from the building ($\hat{C}$) is nearly equal to the resulting interpolation between the highest measured concentrations at 0.3-km and 1-km arcs from releases near the building.

Figure 19 presents data for the stack release. The measurements are clustered 200–300 per cent higher than model estimates. The decrease in concentrations with downwind distance follows the rate of the model. Each grouping by stability classes A, B and E is offset in concentration value (vertical axis) by a similar factor. This result suggests that there is a shift toward a condition of more stable representation, thereby contradicting the observed behavior of growth in the lateral dispersion parameters.

Average measured values for noted groupings are presented in Figs 18 and 19. The form of the model estimates agrees with the form of the measured average values. However, the measured average concentrations are unexplainably a factor of 2–3 higher than the model estimates. Barring an error in the tracer concentration calibration, special flow phenomena as discussed for analyses in the previous section (Johnson *et al.*, 1975) must exist.

Start et al. (1980). A study of simultaneous release of three tracer gases (SF_6, F_{12} and Freon-12B_2) at three levels around the EOCR test reactor building at the Idaho National Engineering Laboratory in southeast Idaho was reported by Start *et al.* (1980). The main building was 25 m high and an effective width, W_b, of 25 m was used for the analyses of the roof stack releases. For the ground-level release, W_b = 50 m was used to account for all the smaller nearby buildings. The nearby terrain was flat with low-lying shrubs. Hourly averaged concentrations were sampled along five concentric arcs. Data from the four outermost arcs were used in this report. Twenty-two test cases were conducted. Only cases that had a 10-m elevation wind speed greater than 3 m s^{-1} and a standard deviation in wind direction of less than 20° were used here (i.e. 14 cases). Discussion in the field study report clearly shows that wind meander during many of the cases may have predominated over any building influence. This subset of the data was chosen because it might be better for evaluating the model since no enhancement is made in situations where the plume dispersion

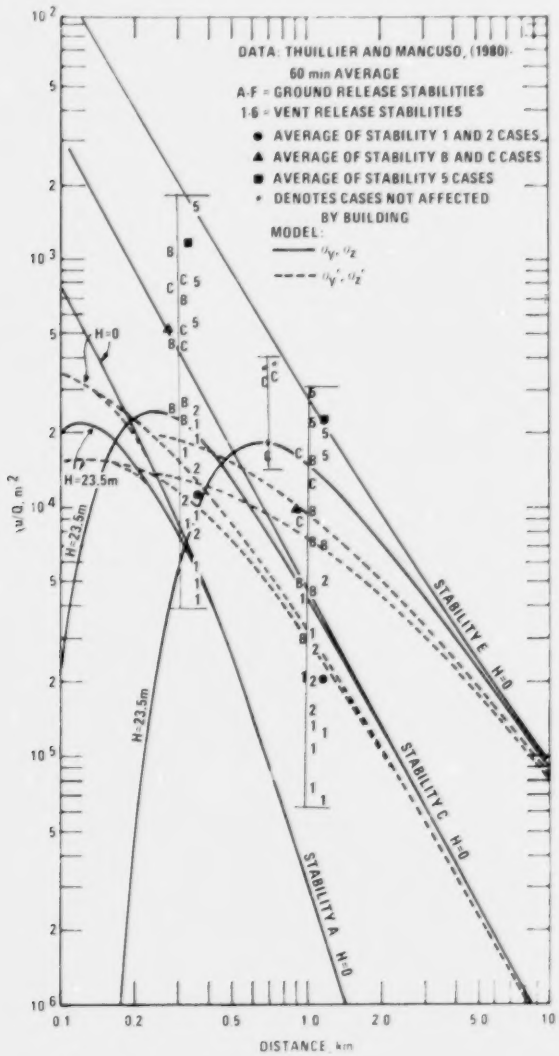

Fig. 18. Comparison of model estimates with measured concentrations for ground and vent release (Thuillier and Mancuso, 1980).

caused by wind meander is greater than the chosen building scales. The NRC stability classification is used.

Figures 20 and 21 present the model comparisons with the measured lateral dispersion parameters. In general, the growth with distance follows that expected for very unstable stability class A conditions. Perhaps plume meander is the dominating factor in this situation.

Figures 22 and 23 present the comparisons of concentrations. For the ground-level release, the model appears to provide an upper bound to the measured values. The same is true for the elevated releases, except for a few very high values. The wiggly line connects values for one case that has a wind speed a factor of two greater than that for the other cases *and* that has the smallest wind direction variance. The measured ground-level concentrations for this case are quite different. Apparently the plume remained along a constant path with no significant diffusion, which is rather unusual. The average measured values for the remaining stable cases closely agree with the model estimate when ambient stability class A is assumed for calculation of the lateral dispersion parameter. This assumption is supported by most of the measured lateral dispersion parameters. (Figs 20 and 21).

Engineering-Science (1980). Two studies of dispersion of tracer (SF_6) from operating natural gas compressor stations were reported for two different sites. The normal heights of stacks (H_s) at each station were approximately the height of the building. The effluent

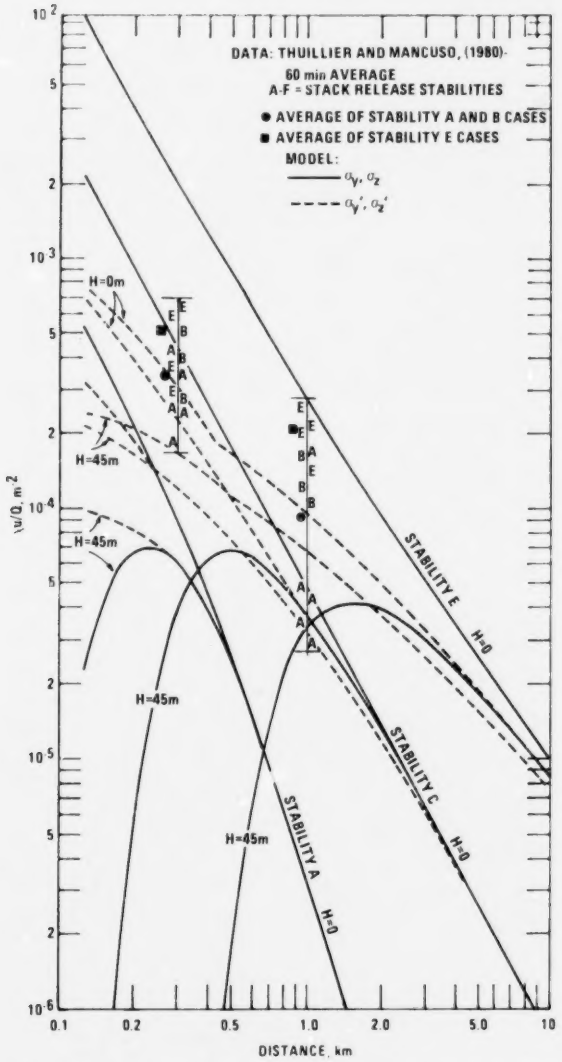

Fig. 19. Comparison of model estimates with measured concentrations for stack release (Thuillier and Mancuso, 1980).

from these stacks normally had a temperature of 600–650 K and an exit velocity greater than 8.8 m s^{-1}. For some test cases at each site, an extension to the stack was added to provide a comparison to the results for the normal height.

Site 1 was a small compressor station located 50 miles from the coast in south Texas. The nearby terrain was flat with a smooth surface, and the building was 13.5 m by 29.3 m by 11.4 m high, with W_b estimated to equal 22.4 m. The stack was located along the south side of the longer building dimension. The results from 40 cases were evaluated. Both plume dispersion parameters and the plume ground-level centerline concentrations were reported for as many as four arcs and are used in this report for comparison with model estimates.

Similar data were reported and analyses were performed for 12 cases at Site 2, a large compressor station in Kansas. The compressor building was 12.8 m × 70.1 m × 12.2 m high, with W_b estimated to equal 71 m. The stack was located along the south side of the longer building dimension. The nearby terrain was flat; however, trees and other buildings were located south of the building.

These studies are unique among all the studies considered in this report because significant plume rise was expected. The extra variable introduced by plume rise should add additional complications. Figure 24

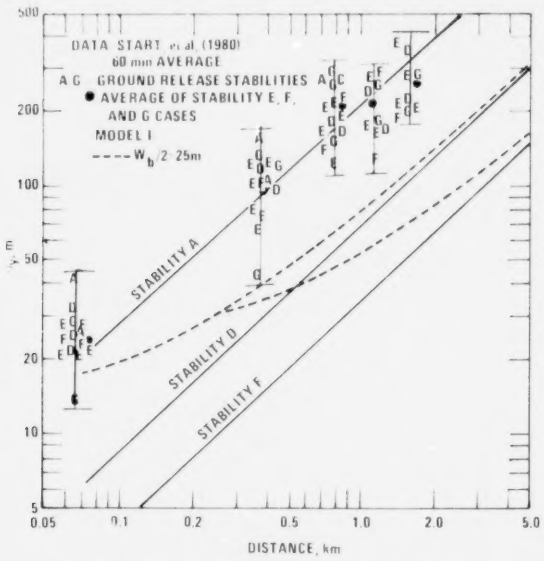

Fig. 20. Comparison of the modified lateral dispersion parameter with field data of Start *et al.* (1980) for ground release.

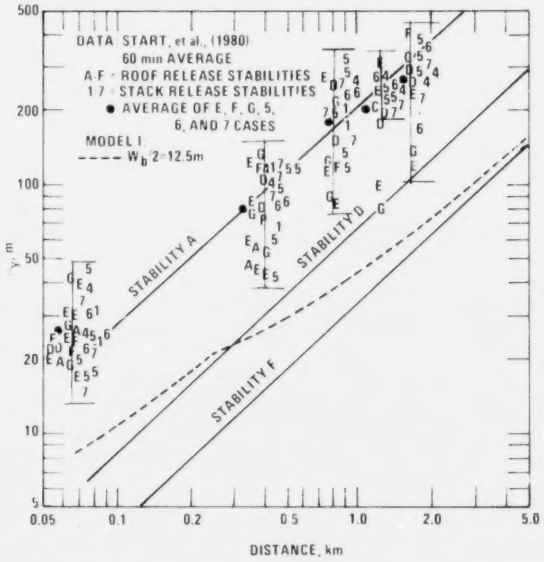

Fig. 21. Comparison of the modified lateral dispersion parameter with field data of Start *et al.* (1980) for roof and stack release.

compares the lateral dispersion parameters for Site 1. Many of the cases have a growth rate greater than that for stability class B. A few cases tend toward the smaller model estimated value while one case has very low values. No apparent difference exists between the measurement for the shorter and the taller stack. Figure 25 compares the concentrations. The 30-min average concentrations were generally measured under meteorological conditions different from those for the 10-min samples.

The following discussion is centered around comparisons made for several categories. Each case is unique because of the influence of wind speed on plume rise. Thus, model estimates should be only generally applicable. Model concentration estimates including plume rise for stack heights (H_s) equal to

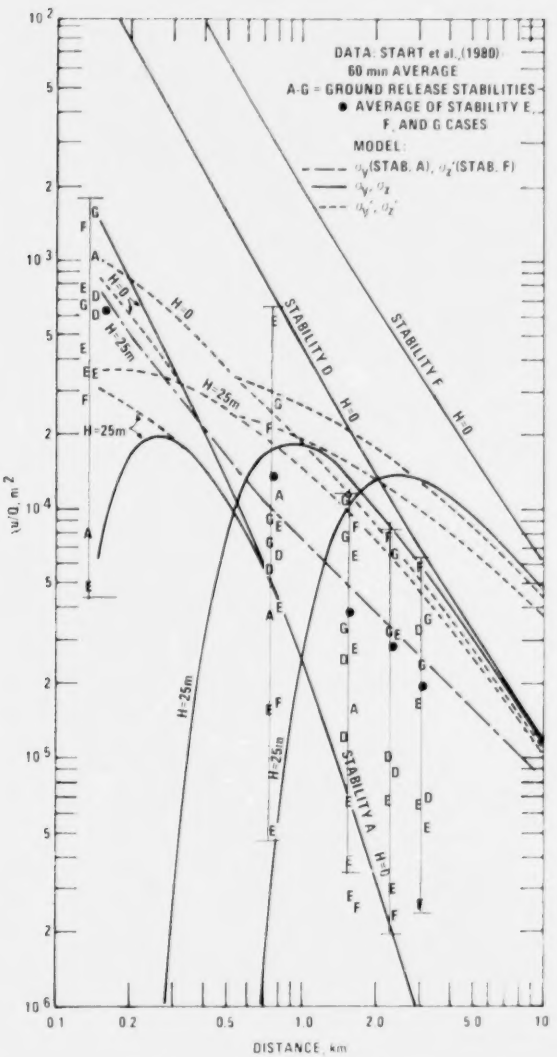

Fig. 22. Comparison of model estimates with measured concentrations for ground release (Start *et al.*, 1980).

9.75 and 14.48 m assume an effluent velocity, W_s, equal to 8.8 m s^{-1}, an effluent temperature, T_s, equal to 636 K, a stack diameter, D_s, equal to 0.6 m, an ambient temperature, T_a, equal to 300 K, and a mean wind speed at the 10-m level, U, equal to 4 m s^{-1} for stability class B and $U = 9$ m s^{-1} for stability class D. Briggs' (1975) plume rise equation is used to calculate the plume centerline height.

In Fig. 25, the average concentrations for stability classes C and D are given for both $W_s = 8.8$ and 15.2 m s^{-1}. Only these two groupings provided more than four values for calculating a mean. The model estimates are made using the estimated effective stack height. The mean values for $W_s = 8.8$ m s^{-1} closely agree with the model estimated curve for a stack height of 9.75 m. The mean values for $W_s = 15.2$ m s^{-1} are lower and similar to model estimates for a slightly higher stack (see curve for $H_s = 14.48$ m). The measured individual concentrations for $H_s = 14.48$ m and stability classes 3 and 4 are in closest agreement with the model curve that assumed enhancement only in the vertical dispersion parameter. This finding is consistent with the wind tunnel observations by Huber *et al.* (1980). In the wind tunnel tests for an elevated release, the plume was significantly laterally enhanced at ground level even though the plume was not enhanced laterally above the height of the building. A similar situation may exist in this field study. For stability classes A and B, this issue is not important because ambient lateral plume dispersion is assumed

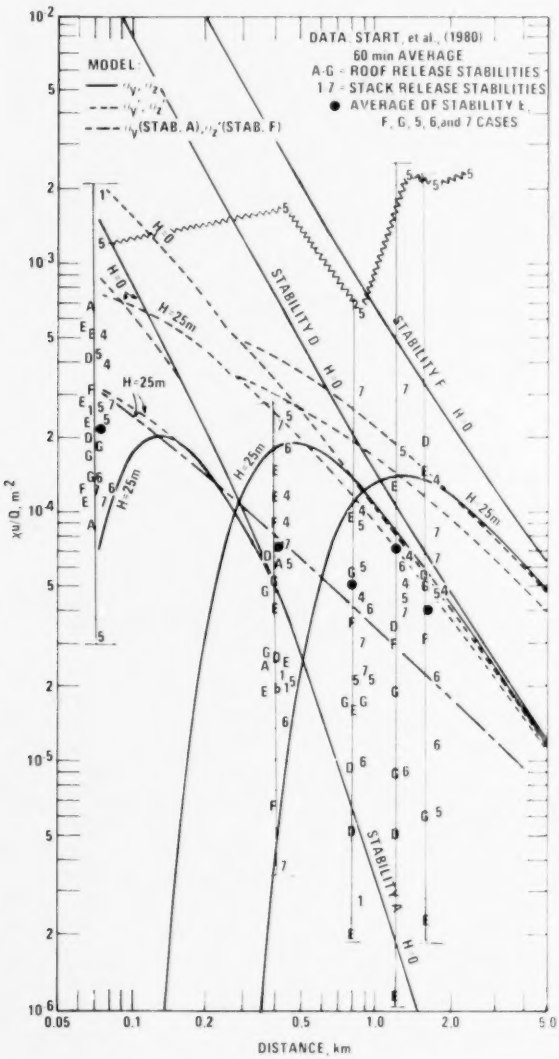

Fig. 23. Comparison of model estimates with measured concentrations for roof and stack release (Start *et al.*, 1980).

to be greater than the model estimate, and thus used instead of the Model I estimate. For stability class A and B cases, wind speeds are lighter and plume rise is a more significant factor. The kinks in the model curves for $H_s = 14.48$ m were caused by the sensitivity of plume concentrations to increasing vertical dispersion versus the rising plume centerline height that occurred downwind. About half of the measured concentrations for stability class A and B (1 and 2) cases agree with the model curve. The remaining measured concentrations are for cases with lowest wind speed and greatest measured lateral dispersion, which should both tend to result in smaller concentrations. Overall, the model equation gives values comparable to the data for Site 1. An examination of plume rise and the effect of plume rise in the wake of buildings needs to be more fully evaluated.

Figure 26 compares the measured lateral dispersion parameters for Site 2. The measured values are clustered together at the 0.05-km arc and scattered at the farther arcs. A model curve assuming *a posteriori* that $W_b = 50$ m (i.e. $4H_b$) would be in fair agreement with several of the cases. Differences between the measured values of the two stack heights are not apparent.

Figure 27 presents the comparison of the measured ground-level concentrations. Model comparisons are made for several categories. Model estimates for stack heights $H_s = 9.8$ and 24.4 m assumed $W_s = 8.1\ \mathrm{m\,s^{-1}}$, $T_s = 616$ K, $D_s = 0.6$ m, $T_a = 300$ K and $U = 2\ \mathrm{m\,s^{-1}}$ for stability class A, $U = 4\ \mathrm{m\,s^{-1}}$ for stability class C

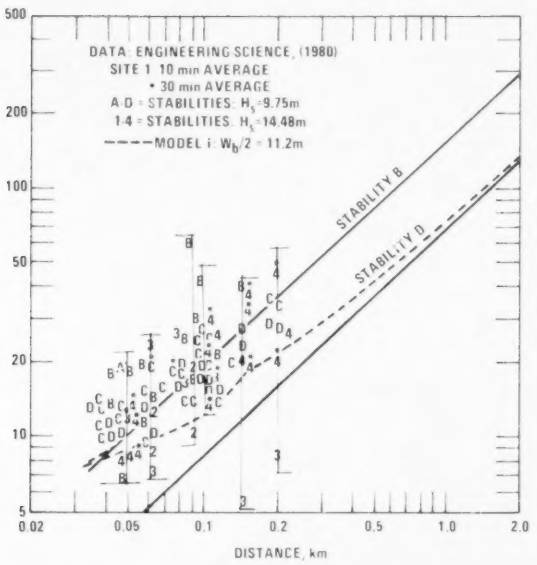

Fig. 24. Comparison of the modified lateral dipersion parameter with field data of Engineering-Science (1980) for Site 1.

and $U = 1.5\,\mathrm{m\,s^{-1}}$ for stability class E. The highest concentrations for the shorter stack are in fair agreement. However, the measured concentrations decrease more rapidly with distance than the model estimate concentrations. This pattern is inconsistent with the normal effects of buildings. The rapid decrease in concentrations is more typical of the effect of very turbulent ambient conditions or measurements missing the true maximum centerline value. The highest concentrations for the taller stack show good agreement with the estimates that assumed stability class C and only enhancement of the vertical dispersion parameter. This pattern is consistent with the observation for Site 1. However, for most of the cases, the concentration values and pattern are in poor agreement with the model. The measured pattern is most similar to that pattern resulting from an elevated source that has not been well mixed to the surface or where the true maximum ground-level centerline was not measured.

4. SUMMARY AND RECOMMENDATIONS

A simple method (Model I) for estimating the enhanced dispersion in the wake of buildings can be easily incorporated into the Gaussian plume equation and requires minimal input data (i.e. building height and width). The method modifies the assumed ambient dispersion parameters to account for the overall influence of the building or other obstacle. Thus, model concentrations using this method should not be expected to perform better than models obtained in the absence of special building influences. Table 1 presents a summary of the comparisons of ground-level centerline concentrations for the 10 field studies. The comparisons are considered to be good, if most measured values (or the mean in some studies) were in agreement; fair, if the patterns of the maximum measured values were in agreement; or poor, if the patterns of measured values were inconsistent with the model estimate. Concentration values within a factor of two are considered to be in good agreement.

The emphasis of the analyses, evaluation of the physical principles of the modifications, can best be accomplished by looking at the pattern of measured values as presented in the figures. The key overall observation of this evaluation is that the observed concentration decay rate downwind of buildings closely follows the modeled rates. In several of the studies, the measured lateral dispersion parameters were observed to be represented by very unstable ambient conditions. For these cases, the building scales were usually less than the ambient lateral dispersion parameters; therefore, no modifications were made. For those studies with stack height above the building, estimated concentrations were better when the lateral dispersion parameter was not modified. Elevated lateral profiles of concentration are needed to verify this assumption; however, it is consistent with wind tunnel study observations.

The methods discussed in this report appear to provide as easily applied first-order plume dispersion correction for the effects of building wake. However, each set of field data represents a unique situation for which a site-specific model would be preferable. Site-specific field data or fluid models could be used to

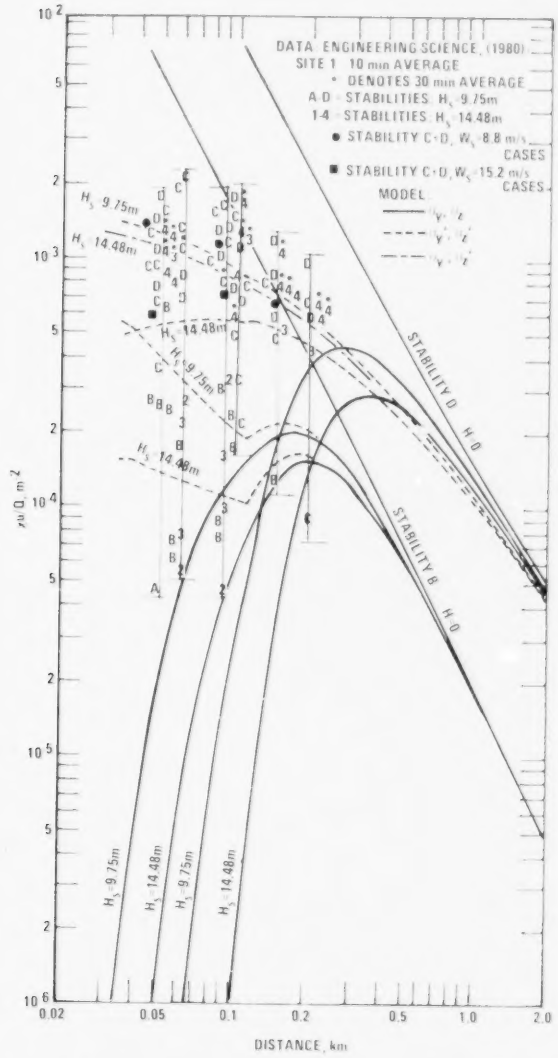

Fig. 25. Comparison of model estimates with measured concentrations for Site 1 (Engineering-Science, 1980).

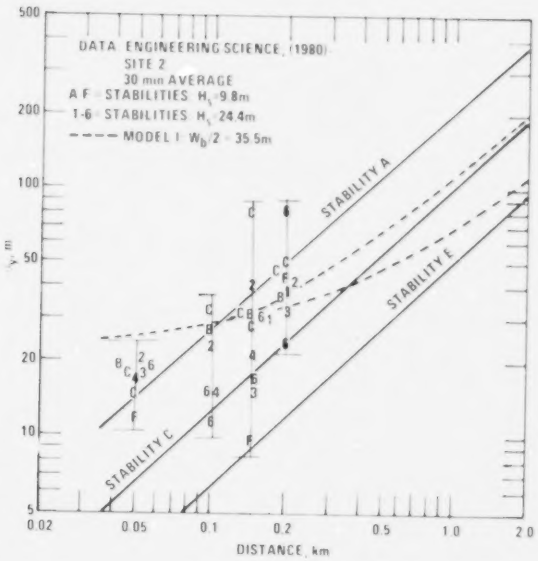

Fig. 26. Comparison of the modified lateral dispersion parameter with field data of Engineering-Science (1980) for Site 2.

Table 1. Summary of studies

	Study*	Tracer	H_b, W_b (m)	H_s (m)	Average (min)	Stability	Number of Cases	Concentration Comparisons: Form	Concentration Comparisons: Values
1	Islitzer (1965)	Fluorescent	25, 160	0	30-60	A	9	Good	Good
2	Martin (1965)	Krypton-85	14,	20	2-5?	C-D	2	Good	Fair
3	Dickson et al (1967)	Fluorescent	30, 130	0	30	C-D	8	Good	Good
4	Munn and Cole (1967a)	Fluorescent	18, 93	30	20	D	11	Poor	Poor
5	Munn and Cole (1967b)	Uranine Dye	28, 100	50	15	D	11	Fair	Fair
6	Cagnetti (1975)	Uranine Dye	16, 100	20	30-60	A	4	Fair	Poor
7	Johnson et al (1975)	SF6	49, 65	50	60	D	22	Good	Poor
8	Thuillier and Mancuso (1980)	SF6	24, 130 43, 40	0 24 45	60 60	A-E A-B, E	27 12	Fair Good	Poor Poor
9	Start et al (1980)	SF6, F12, 12B2	25, 25 25, 50	25, 30 0	60 60	E-G E-G	14 14	Good Good	Fair** Good**
10	Engineering-Science (1980)	SF6	11 4, 22 4	9 75 *4 48	10-30	A-D	28 14	Good Good	Good** Good**
			12 2,71	9 88 24 4	30	A-F	5 7	Fair ?	Fair Poor

*Individual Study Notes

2 one case is like a ground-level source estimate

4 a) all cases are like no building effects estimates
b) maximum is likely beyond the range of measurements
c) sparse sampler network near other buildings

5 sparse sampler network

6 tracer intercepting buildings between release and samplers may be deposited or diverted away from samplers

7 measured values are much larger for all cases with higher wind speed

8 mean values are a constant factor higher than estimates for all groupings

10 a) uncertainty in plume rise
b) low measured values may be caused by reduced building effects for cases with high plume height

** Applies to average values

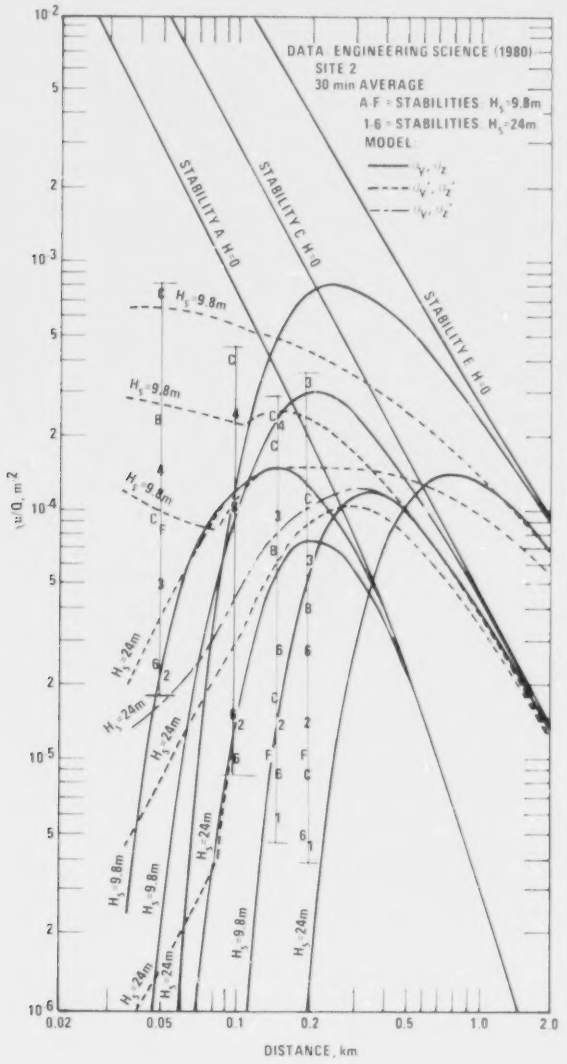

Fig. 27. Comparison of model estimates with measured concentrations for Site 2 (Engineering-Science, 1980).

provide better initial dispersion patterns for estimating the virtual source distances. The simple technique of Model I for estimating the enhanced dispersion parameters is most applicable for estimating the effects of an isolated obstacle upon a nearby release when the path to the receptor is unobstructed. An array of buildings must be examined to determine the most significant height and width scales. Additional horizontal enhancement must also be considered if other buildings are situated further downwind, where the plume can spread into their wake as well. Also, for such situations, the downwind buildings may have a different height from the building that initially affected the plume. The downwind buildings may not have a significant effect if their heights and widths are small relative to plume spread at that point.

Better measurements of plume height and the vertical spread of the plume are still needed to resolve some issues. The effect of building influences on plume rise and the determination of plume centerline require vertical profile measurements. Also the effect of wind speed should be considered. The cases with the highest wind speed have been observed to behave somewhat extraordinarily for several of the studies. Also, the possible effect of vortices should be more fully evaluated. Additional data are needed to fully examine building wake effects. However, in lieu of site-specific information, the methods presented in this report should provide an approximate correction to estimated ground-level centerline concentrations.

REFERENCES

Bowers J. F. and Anderson A. J. (1981) An evaluation study for the industrial source complex (ISC) dispersion model. EPA report 450/4-81-002. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, NC. by H.E. Cramer Company, Inc. Salt Lake City, UT.

Briggs G. A. (1975) Plume rise predictions. In *Lectures on Air Pollution and Environmental Impact Analysis*. Am. Met. Soc., Boston, MA.

Cagnetti P. (1975) Downwind concentrations of an airborne tracer released in the neighborhood of a building. *Atmospheric Environment* **9**, 739–747.

Culkowski W. M. (1967) Estimating the effect of buildings on plumes from short stacks. *Nucl. Saf.* **8**, 257–259.

Dickson C. R., Start G. E. and Markee E. H., Jr. (1967) Aerodynamic effects of the EBR-II containment vessel complex on effluent concentration. USAEC Meteorological Information Meeting, Chalk River, Canada, AECL-2787, 87-104. Also, *Nucl. Saf.* **10**, 228–242.

Engineering-Science (1980) Field validation of atmospheric dispersion models for natural gas compressor stations. AGA Catalog No. L51387. Prepared for the American Gas Association—Pipeline Research Committee, Arlington, VA.

Gifford F. A. (1968) An outline of theories of diffusion in the lower layers of the atmosphere. Ch. 3.; In *Meteorology and Atomic Energy*—1968 (edited by Slade D. H.). TID-214190, available NTIS, Springfield, VA.

Gifford F. A. (1976) Turbulent diffusion typing schemes: a review. *Nucl. Saf.* **17**, 68–86.

Halitsky J. and Woodward K. (1974) Atmospheric diffusion experiments at a nuclear power plant site under light wind inversion conditions. AMS Symposium on Atmospheric Turbulence and Diffusion Santa Barbara, CA, Am. Met. Soc., Boston, MA, 172–179.

Hosker, R. P., Jr. (1984) Flow and diffusion near obstacles. In *Atmospheric Science and Power Production* (edited by Randerson D.), Chap. 7. U.S. Department of Energy Tech. Info. Center, Oak Ridge, TN (in press).

Huber A. H., Snyder W. H., Thompson R. S. and Lawson R. E., Jr. (1980) The effects of a squat building on short stack effluents—a wind tunnel study. EPA report 600/4-80-055. U.S. Environment Protection Agency, Research Triangle Park, NC.

Huber A. and Snyder W. (1982) Wind tunnel investigation of the effects of a rectangular-shaped building on dispersion of effluents from short adjacent stacks. *Atmospheric Environment* **16**, 2837–2848.

Islitzer N. F. (1965) Aerodynamic effects of large reactor complexes upon atmospheric turbulence and diffusion. USAEC Report IDP-12041, Weather Bureau, Idaho Falls, ID.

Johnson W. B., Shelar E., Ruff R. E., Singh H. B. and Salas L. (1975) Gas tracer study of roof-vent effluent diffusion at Millstone Nuclear Power Station. Prepared for Atomic Industrial Forum, Inc., Report No. AIF/NESP-007b, Stanford Research Institute, Menlo Park, CA.

Lawson T. V. (1967) Turbulence and diffusion in the wake of a building. *Atmospheric Environment* **1**, 177–181.

Martin J. E. (1965) The correlation of wind tunnel and field measurements of gas diffusion using Krypton-85 as a tracer. Michigan Memorial Phoenix Project, MMPP272, University of Michigan, Ann Arbor, MI.

Meroney R. N. (1982) Turbulent diffusion near buildings. In *Engineering Meteorology* (edited by Plate E. J.), chap. 10. Elsevier Scientific Publishing Company, Amsterdam.

Munn R. E. and Cole A. F. W. (1967a) Turbulence and diffusion in the wake of a building. *Atmospheric Environment* **1**, 33–43.

Munn R. E. and Cole A. F. W. (1967b) Some strong-wind downwash diffusion measurements at Douglas Point, Ontario, Canada. *Atmospheric Environment* **1**, 601–604.

Snyder W. H. and Lawson R. E., Jr. (1976) Determination of the necessary height for a stack close to a building—a wind tunnel study. *Atmospheric Environment* **10**, 683–691.

Start F., Cate J. and Dickson C. (1977) Rancho Seco building wake effects on atmospheric diffusion. Air Resources Laboratories, Idaho Falls, ID. NOAA, Technical Memorandum ERL ARL-69.

Start G. E., Hukari N. F., Sagendorf J. F., Cate J. H. and Dickson C. R. (1980) EOCR building wake effects on atmospheric diffusion. Air Resources Laboratories, Silver Spring, MD, NOAA Technical Memorandum ERL ARL-91.

Thompson R. S. and Lombardi D. J. (1977) Dispersion of roof-top emissions from isolated buildings—a wind tunnel study. EPA report 600/4-77-006. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Thuillier R. H. and Mancuso R. L. (1980) Building effects on effluent dispersion from roof vents at nuclear power plants. Prepared for Electric Power Research Institute, Report EPRI NP-1380, by SRI International, Menlo Park, CA.

Turner D. B. (1970) Workbook of atmospheric dispersion estimates. Office of Air Programs, Publication No. AP-26, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Vincent J. H. (1977) Model experiments on the nature of air pollution transport near buildings. *Atmospheric Environment* **11**, 765–774.

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